91602
new 82-10

ontario hydro
research division

TRANSMISSION LINE REFURBISHMENT STUDY: TESTS ON McGUIGAN TYPE STEEL TRANSMISSION TOWERS - OAKVILLE

Report No. 90-192-K

S.G. Krishnasamy*, C.J. Pon*
M.Tabatabai*, G.A. Senkiw*
H.S. Radhakrishna**, R.H.K. Tsang**
H.Dey#, M.Vanderbrug#, I.Boulos#

ABSTRACT

As part of the ongoing transmission line refurbishment study, two double circuit 115 kV, McGuigan type steel suspension towers on grillage foundations, built in 1911, were tested to failure. The type of loads applied on these towers were chosen to represent unbalanced loads due to broken conductor, heavy ice, strong wind and wind-on-ice loads. Tower structure and foundation were appropriately instrumented to measure the member loads, tower deflections and foundation loads and movements. The correlation is good between the predicted and actual 1) tower failure loads, 2) tower member loads, and 3) foundation loads. The tower tests confirmed that a certain amount of upgrading to the tower structure is necessary to bring it to the required strength level. The effect of foundation movement was negligible on the overall tower strength.

---

* Mechanical Research Dept.
** Civil Research Dept.
# Transmission Lines Design Dept.

job	file	date	report no.
21-281-431	825.151	August 24, 1990	90-192-K

91602
new 82-10

ontario hydro
research division

EXECUTIVE SUMMARY

TRANSMISSION LINE REFURBISHMENT STUDY: TESTS ON McGUIGAN TYPE STEEL TRANSMISSION TOWERS - OAKVILLE

S.G. Krishnasamy*, C.J. Pon*
M.Tabatabai*, G.A. Senkiw*
H.S. Radhakrishna**, R.H.K. Tsang**
H.Dey#, M. Vanderbrug#, I.Boulos#

As part of Ontario Hydro's transmission line refurbishment program two series of tower tests were carried out. The first series of tests were done on Kingston type (1928) towers near Smiths Falls and the second were done on McGuigan type (1911) towers at Oakville. This report deals with the tests done on the McGuigan type towers.

At Oakville two double circuit 115 kV, McGuigan type steel suspension towers on grillage foundations were tested to failure. One of the towers tested at Oakville was upgraded with new members added on to it. The type of test loads applied on these towers were chosen to represent unbalanced loads due to broken conductor, heavy ice, strong wind and wind-on-ice loads. Tower structures and foundations were appropriately instrumented to measure the member loads, tower deflections and foundation loads and movements. The correlation is good between the predicted and actual 1) tower failure loads, 2) tower member loads, and 3) foundation loads. The tower tests confirmed that a certain amount of upgrading to the tower structure is necessary to bring it to the required strength level. The effect of foundation movement was negligible on the overall tower strength.

JC

* Mechanical Research Dept.
** Civil Research Dept.
# Trans. Lines Design Dept.

job	file	date	report no.
21-281-431	825.151	August 24, 1990	90-192-K

91-03179/

ontario hydro
research division

To D.E. Horrocks
Manager, Transmission Lines Programs
Design and Development - Transmission

TRANSMISSION LINE REFURBISHMENT STUDY:
TESTS ON McGUIGAN TYPE STEEL
TRANSMISSION TOWERS - OAKVILLE

INTRODUCTION

There are about twenty families of transmission towers in use in Ontario Hydro on lines built before 1940 which are within the overall refurbishment program. Two of the more widely used tower types are being tested to assess their condition and to calibrate the assessment of their strengths using available design techniques.

In the spring of 1988, as part of Ontario Hydro's transmission line refurbishment program, three single circuit 115 kV, Kingston type towers on rock-anchor foundations were tested to failure/1/. The type of loads applied on the towers were chosen to represent unbalanced loads due to broken conductor, heavy ice, high wind and wind-on-ice loads. Selected tower members and foundations were instrumented to measure the member loads, tower deflections and foundation movements during the various stages of testing. The tower tests confirmed that there is reserve strength available for upgrading the conductor on this line.

In the summer of 1989, as part of the same tower refurbishment program, two McGuigan type steel transmission towers were tested to failure. In this series of tests combinations of vertical and along-the-line loads were used to simulate the effect of loading due to heavy ice, strong wind, broken conductor and wind-on-ice conditions. The test site, consisting of two McGuigan type towers, located at Oakville, Ontario was selected for the project.

This report deal with the tests carried out on the McGuigan type towers. Since most of the instrumentation and test procedure used in this project were similar to those used in the tests on Kingston type towers/1/, only the differences will be discussed in some detail in this report. The data gathered during these tests have been analyzed to determine the strength of towers and foundations.

DESCRIPTION OF TOWERS

The dimensions of the McGuigan type suspension towers are given in Figure 1 and a typical view of it is shown in Figure 2. These towers were built in 1911 and most of its joints were made by bolting the steel angles together. Tensile tests on coupons cut from selected tower members showed that the yield and ultimate strength of the steel used were 279 MPa and 424 MPa respectively and the modulus of elasticity was 207000 MPa.

INSPECTION OF TOWERS AND FOOTINGS

Prior to preparing the towers for testing, each tower was closely inspected for damaged steel members and missing bolts and were replaced wherever possible. The tower footings were also inspected to assess the type of foundation and soil.

TYPES OF LOAD APPLIED

The following three basic load types were used to test the two towers:

1) Vertical load
2) Broken conductor load
3) Along-the-line load applied to the tower shaft to simulate the effect of across-the-line loads

These basic load types were combined as shown below to simulate the design loads applied on the towers:

a) Heavy ice represented by load type (1)
b) Broken conductor (top or bottom arm), represented by combining load types (1) and (2)
c) High wind and wind-on-ice, represented by combining load types (1) and (3)

Load type (3) was also used to simulate the effect of loading due to line angle. The various load combinations are shown in Figures 3 and 4. The maximum loads applied to each tower under different load combinations are summarized in Table 1. The detailed load steps used for testing Towers 14 and 13 are given in Appendices 1 and 2. The test procedures and the arrangements for applying various loading combinations are described in detail in /1/. Figures 5 and 6 show the application of different loads to the towers tested at Oakville.

Tower 14 was tested without any changes to the original structure or foundation to determine its remaining strength. However, Tower 13 was tested with reinforcement to the structure at selected locations(Figure 7) and to the foundation to improve overall tower strength and prevent any premature failure. The purpose of this test is also to evaluate the strength of the reinforced tower without causing the foundation to fail prior to tower failure. The uplift footings were restricted with anchors while the compression footings were reinforced with steel beams resting on the ground.

INSTRUMENTATION AND MEASUREMENTS

The measuring system consisted of load cells, strain gauges, displacement transducers and a weather monitoring package. The data acquisition system consisted of data loggers, signal conditioners, microcomputers and printers. Since the systems are similar to those used in the tests on Kingston type towers the detailed accounts of these can be found in /1/. The various gauge locations on the McGuigan type towers tested are shown in Figure 8, and a typical gauge installation is shown in Figure 9. Also shown, Figure 10, is a typical installation of instruments to measure foundation movements.

The following are the typical measurements made during a tower test:

- Strain in selected tower members including the the tower leg members by means of strain gauges
- Loads applied to towers at conductor and skywire attachment points by using load cells
- Foundation movements by means of transducers and soil uplift by 'Tell Tale' points

- Tower joint deflections using a geodimeter
- Wind speed,direction and temperature at the site using a portable weather station

Most of these measurements were continuously recorded by digital data logging systems for further analysis.

DATA ANALYSIS AND DISCUSSION

The following parameters were recorded to evaluate the behaviour of tower structure and foundation under various loading conditions:

Tower steel temperature
Wind speed and direction
Ambient temperature
Strain at selected locations on tower members
Foundation displacement at all legs
Applied vertical and along-the-line loads (Figs.3&4)
Angle at which along-the-line loads were applied
Tower displacement at selected locations (Fig.1)

The information gathered from all the tests on the two towers were used to perform the following analyses:

1) Compare predicted and actual tower failure loads
2) Study tower deflections under different loads
3) Examine foundation deflections under different loads
4) Compare measured and predicted loads in selected tower members.

Comparison of Measured and Predicted Tower Member Loads

Several important members of each tower were instrumented to assess the loads carried by them during various tests. Table 2 contains the measured and predicted loads on selected tower members just prior to failure. A computer program based on linear elastic analysis was used to predict the member loads. Also included in Table 2 are the percentage ratio between the measured load on each member and its load carrying capacity. These ratios show the extent to which the members were loaded with respect to their load carrying capacity. The loads on the members were calculated from the measured strains by applying the structural and material properties of members. Only members subjected to relatively high loads, compared to their yield or buckling strength, were considered. Members subjected to relatively lower loads are of less importance and therefore are not considered. The maximum difference between the measured and predicted tower member loads is 17%. The maximum load on the strain gauged members was about 76.5 kN.

Considering the assumptions involved both in the computer analysis and in the experimental procedures and the structural and loading asymmetry, the extent of correlation is very satisfactory.

Study of Tower Deflections

Table 3 shows the three (along-the-line, across-the-line and vertical) components of the maximum measured tower deflections during each test. The table also lists the joints at which the deflections were measured and the corresponding load levels.

The maximum measured deflections for Towers 14 and 13 were 181 mm and 135 mm respectively and in both towers these deflections occurred under the broken-conductor (top arm) loading case. It should be noted that the maximum deflection measured during the high-wind loading condition corresponds to 72 %

and 98 % of the actual maximum load applied (Table 1) on Towers 14 and 13 respectively. Therefore it is difficult to state the absolute maximum deflections of the tower joints just prior to failure, particularly for tower 14. The measured deflections include the effects of slippage at the joints, local yielding, etc. which are probably not considered in the analysis.

Study of Tower Foundation Load and Displacements

The measured foundation loads derived from the loads on strain gauged members were within 17% of the predicted values based on simple static equilibrium (Table 4). The foundation reactions are not significantly affected by the tower deflections provided the overall tower stability is maintained.

Table 5 summarizes the measured tower leg movements at the ground level under various maximum loading conditions. For Tower 14 without a reinforced foundation, the settlement and uplift movements measured were 10 mm or less for all loading conditions. The lateral movements of the tower legs for Tower 14 exceeded 12.5 mm for loading cases 3 and 4 (Table 5). Maximum lateral movements (28 mm) of the tower legs at groundline were measured just prior to tower failure (Tower 14, Test No 4). For the load step just prior to tower failure (Tower 14, Test No 4), maximum uplift and compression loads were measured ranging from 77 and 82 kN respectively. This maximum uplift load (77 kN) for Tower 14 corresponds to 75 to 100% of the ultimate uplift capacity determined from other grillage load tests/2/. The allowable uplift load for these site conditions was estimated to range from 60 to 80 kN at 25 mm deflections (personal communique with F. Devisser, D&D Transmission, TL Design). No grillage compression load tests were performed for comparison purposes.

Tower 14 was instrumented with telltales in the backfill material and native soil. No uplift movements of the backfill material above the grillage pads were recorded to indicate a general mode of failure had occurred (i.e., inverted truncated cone). Instead, the backfill directly above the grillage members was locally compressed by a maximum of approximately 10 mm under maximum loading prior to tower failure.

The shear load at the groundline for each tower leg was estimated to be 12 kN for Tower 14. The corresponding groundline deflection for a shear load of 15 kN from grillage load tests at Tower 15 was approximately 25 mm/3/.

Tower 13 was reinforced with 4 helix anchors attached to the uplift legs and extra steel beams on the compression legs. The foundation at Tower 13 was reinforced to minimize foundation movements in order to assess the structural integrity of the tower (Table 5). The maximum foundation reactions measured in uplift ranged from 77 to 81 kN and in compression from 82 kN to 94 kN prior to tower failure.

Tower Failure Loads

The tower failure loads were calculated based upon an analysis program /1/ used in Ontario Hydro. The predicted and measured tower failure loads are given in Table 6. The tower is considered to have failed when its capability to sustain loads is lost. It is seen from the table that there is a good correlation between the predicted and measured failure loads, the maximum difference being less than 3%.

As planned both the towers failed under the wind-on-ice load condition. However, one of the arms in Tower No.14 failed prematurely below the expected design load and thus may require reinforcement. Nevertheless the overall strength of the tower was not affected. The good correlation between the predicted and the actual failure loads shows that the effect of foundation displacement is minimal on the overall tower strength.

Based on the information and experience gained from the tests on Tower No.14 certain members of Tower No.13 were reinforced to improve the overall strength. The changes made to Tower No.13 are shown in Figure 7. The foundation movements of Tower No.13 were also restricted to minimize the interaction

between foundation and tower structure and thus determine the 'absolute' tower strength. Again it can be seen from the excellent correlation between the predicted and actual tower strengths the effect of structure - foundation interaction is minimal on the overall tower strength. The higher strength of Tower No.13 (63.8 kN) compared to that of Tower No.14 (52.1 kN) show that the reinforcement has helped to enhance the tower capacity. The tests also indicate that the margin of strength in the towers is minimum for the tested loading conditions.

Two views of a typical tower failure are shown in Figure 11.

CONCLUSIONS

The analysis of the data gathered from the tests on Tower 14 and Tower 13 have led to the following conclusions:

1) The correlation is good between the predicted and actual tower failure loads; the maximum difference is about 3%
2) The arm of Tower 14 failed due to a slightly lower than anticipated load and hence requires reinforcement.
3) The extent of correlation is satisfactory between the calculated and measured tower member loads.
4) The agreement is satisfactory between the measured and predicted foundation loads.
5) In some loading cases the foundation movement of Tower 14 slightly exceeded the allowable limits. Its effect on the load carrying capacity of the tower was negligible.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance provided by the following staff during the various stages of the tower testing program: Messers R.W. Wolfendale, M. Kastelein, G. O'Reilly, D. Mitchell, D. King, D. Austin and the construction staff of the Central Region.

Reviewed by:

J.A. Chadha
Supervising Engineer
Applied Mechanics Section
Mechanical Research Dept.

Submitted by:

S.G. Krishnasamy
Unit Head-Transmission,
Distribution & Structures
Applied Mechanics Section

Approved by:

G.J. Clarke
Manager
Mechanical Research Department

REFERENCES

1) S.G. Krishnasamy, "Transmission Line Refurbishment Study: Tests on Kingston Type Steel Transmission Towers - Smiths Falls", Ontario Hydro Report No. 89-79-K, June 1989.

2) R.H. Tsang and H.S. Radhakrishna, "Uplift Test on Grillage Footing for Tower 13 and 14 Halton Junction to Old Cooksville T.S.'B 115 kV Line", Ontario Hydro Report Under Preparation.

3) R.H. Tsang and H.S. Radhakrishna, "Transmission Line Refurbishment Study: Tower Foundation Testing and Inspection Halton Junction to Old Uplift Test on Grillage Footing for Tower 13 and 14 Halton Junction to Old Cooksville T.S.'B 115 kV Line", Ontario Hydro Report No. 89-139-K, June 1989.

TABLE 1

DETAILS OF APPLIED LOAD CONDITIONS ON TOWERS 14 AND 13

Tower No.	*Test No.*	*Type of Load Applied*	*Maximum Load Applied (kN)*		*Figure No.*
			Vertical	*Horizontal*	
14	1	Heavy ice and wind-on-ice**	52	39	3(A)
	2A*	Broken conductor - bottom arm	9	25	3(B)
	2B*	Broken conductor - top arm	16	30	3(C)
	3	Broken conductor - 2 bottom arms	16	23	3(D)
	4	High wind**	16	52	3(E)
13	5*	Heavy ice and wind-on-ice**	46	21	4(A)
	6A*	Broken conductor - top arm	23	29	4(B)
	7	High wind**	11	64	4(C)

* Transverse load equivalent to 3 degree line angle is simulated by along-the-line pull on the shaft.

** Simulated by along-the-line pull on the shaft.

TABLE 2

COMPARISON OF MEASURED AND PREDICTED LOADS IN SELECTED TOWER MEMBERS JUST BEFORE TOWER FAILURE

Member ID+	*Member Type*	*Tower 14, Test 4*		*% Diff.**	*% Ratio ***	*Tower 13, Test 7*		*% Diff.[1]*	*% Ratio[2]*
		Measured Load (kN)	*Predicted Load (kN)*			*Measured Load (kN)*	*Predicted Load (kN)*		
D	compression	-69.0	-71.2	-3	85	-76.5	-66.2	16	94
G	tension	55.6	49.0	14	43	62.1	58.9	5	47
L	tension	56.1	49.0	15	43	60.3	53.9	12	46
R	compression	-68.5	-71.2	-4	85	-71.6	-66.2	8	88
BB	tension					18.5	18.2	1	50
CC	tension					25.2	23.6	7	90
DD	compression					-8.0	-9.6	-17	81

\+ **See figure 8.**

1 **% difference** $= 100 * \frac{\text{Measured} - \text{Predicted}}{\text{Predicted}}$

2 **% Ratio** $= \frac{\text{Measured Load}}{\text{Ultimate Load}}$

TABLE 3

MAXIMUM MEASURED TOWER DEFLECTIONS DURING VARIOUS TESTS

Tower No.	Test No.	Target+	Applied Load (kN)			Maximum Deflection (mm)		
			Vertical	Horizontal	Type (Fig.)	Along Line	Across Line	Vertical
14	1	T4	52	39	3(A)	67	10	60
	2A	T8	9	25	3(B)	116	14	21
	2B	T6	16	30	3(C)	181	31	20
	3	T8	16	23	3(D)	132	20	71
	4	T7	12	37**	3(E)	53	7	6
13	5	T6	46	21	4(A)	15	3	22
	6A	T6	23	29	4(B)	135	21	18
	7	T1	10	63**	4(C)	84	11	1

\+ See figure 1.
* Joint at which maximum deflection occurred.
** The last load for which deflection measurements are available.

TABLE 4

MEASURED AND PREDICTED TOWER FOUNDATION LOADS

Tower No.	Test No.	Max. Load Applied (kN)		Measured Load on Foundations (kN)				Predicted Load on Foundation (kN)				Percentage Diff.*			
		Vert	Horiz	NW	NE	SW	SE	NW	NE	SW	SE	NW	NE	SW	SE
14	1	52	31	48	--	-73	-70	43	43	-70	-70	9	--	4	0
	2A	9	25	34	--	-37	-38	32	35	-40	-37	6	--	-7	2
	2B	16	30	44	45	-49	-44	43	44	-52	-51	1	3	-5	13
	3	16	23	27	34	-36	-32	24	34	-42	-31	17	1	-14	2
	4	16	52	77	82	-81	-81	71	71	-79	-79	8	15	3	3
13	5	46	21	-42	-37	17	18	-41	-41	18	18	1	-11	-10	-1
	6A	23	29	-49	-46	39	40	-54	-53	41	43	-9	-12	-5	-6
	7	11	64	-94	-82	77	81	-95	-95	89	89	-1	-13	-13	-9

* Percentage Difference = $\frac{\text{Measured - Predicted}}{\text{Predicted}}$

TABLE 5

TYPICAL MEASURED FOUNDATION DISPLACEMENTS UNDER VARIOUS LOADING CONDITIONS

Tower No.	Test No.	Tower Footing											
		North East			North West			South East			South West		
		Load (kN)	Hor.[1] Dist. (mm)	Vert.[2] Dist. (mm)	Load (kN)	Hor. Dist. (mm)	Vert. Dist. (mm)	Load (kN)	Hor. Dist. (mm)	Vert. Dist. (mm)	Load (kN)	Hor. Dist. (mm)	Vert. Dist. (mm)
14	1	48	8	4	--	8	3	-73	6	--	-70	6	-2
	2A	34	2	--	--	9	3	-37	2	-1	-38	8	--
	2B	44	2	2	45	7	4	-49	-2	--	-44	7	--
	3	27	-2	--	34	16	1	-36	-2	--	-32	6	--
	4	77	28	9	82	11	10	-81	-4	--	-81	20	-1
13	5	-42	1	--	-37	--	--	17	--	--	18	--	--
	6A	-49	2	-2	-46	-2	-2	39	3	--	40	--	2
	7	-94	5	-4	-82	1	-5	77	5	4	81	4	3

1 Resultant Axial (+ Tension, - Compression)
2 Horizontal Displacement (Southward IS + ve)
3 Vertical Uplift (+ ve)

TABLE 6

ACTUAL AND PREDICTED TOWER FAILURE LOADS

Tower No.	*Loading Type*	*Loading Points*	*Actual Load (kN)*	*Predicted Load (kN)*	*Percentage Difference*
14	Along-the-line pull to simulate high wind	Applied to the shaft	52.1	51.6	1
13	Along-the-line pull to simulate high wind	Applied to the shaft	63.8	62.3	2.4

APPENDIX 1

LOAD STEPS FOR VARIOUS LOADING CONDITIONS ON TOWER 14

LOAD STEPS FOR TEST 1: HEAVY ICE AND WIND-ON-ICE CONDITION

Load Steps	Vertical Loads, kN						Along-the-Line Load, kN
	Left Circuit			Right Circuit			
	PT 2*	PT 3*	PT 4*	PT 5*	PT 6*	PT 7*	PT 10*
1 - 1	4.54	4.83	4.76	4.69	4.65	4.41	0.78
1 - 2	7.34	6.99	7.32	6.81	7.23	6.92	0.78
1 - 3	7.92	8.08	7.85	7.88	7.57	8.50	0.78
1 - 4	9.37	9.23	9.12	9.55	9.57	9.46	0.78
1 - 5	9.46	9.21	9.10	9.57	9.46	9.43	8.50
1 - 6	9.41	9.19	9.06	9.55	9.43	9.39	21.00
1 - 7	9.41	9.19	9.08	9.52	9.48	9.39	29.13
1 - 8	9.41	9.17	9.10	9.52	9.48	9.39	35.67
1 - 9	9.37	9.14	9.10	9.52	9.43	9.41	39.56

* See Figure 3a

LOAD STEPS FOR TEST 2A: BROKEN CONDUCTOR (OUTSIDE ARM) CONDITION

Load Steps	Vertical Loads, kN					Along-the-Line Loads, kN	
	Sky Wire	Left Circuit		Right Circuit			
	PT 1*	PT 2*	PT 3*	PT 4*	PT 5*	PT 10*	PT 8*
2A - 1	0.93	1.71	1.78	1.54	1.80	0.69	0.76
2A - 2	0.93	1.71	1.76	1.54	1.80	6.07	1.09
2A - 3	0.91	1.71	1.76	1.51	1.80	11.86	1.02
2A - 4	0.91	1.69	1.76	1.51	1.78	11.61	9.70
2A - 5	0.91	1.74	1.76	1.54	1.82	11.57	11.79
2A - 6	0.93	1.71	1.78	1.54	1.85	11.57	13.75
2A - 7	0.93	1.74	1.78	1.56	1.89	1.54	0.93

* See Figure 3b

LOAD STEPS FOR TEST 2B: BROKEN CONDUCTOR (TOP ARM) CONDITION

Load Steps	Vertical Loads, kN						Along-the-Line Loads, kN	
	Sky Wire	Left Circuit			Right Circuit			
	PT 1*	PT 2*	PT 3*	PT 4*	PT 6*	PT 7*	PT 10*	PT 12*
2B - 1	0.93	1.67	1.78	1.56	1.71	1.69	1.54	0.73
2B - 2	0.91	1.69	1.76	1.54	1.69	1.65	5.87	0.67
2B - 3	0.91	1.74	1.74	1.51	1.67	1.62	11.99	0.65
2B - 4	0.89	1.67	1.74	1.51	1.67	1.60	11.70	10.06
2B - 5	0.89	1.65	1.71	1.49	1.65	1.60	11.61	14.59
2B - 6	0.89	1.65	1.69	1.47	1.56	1.54	11.50	17.84
2B - 7	0.89	1.67	1.74	1.49	1.60	1.62	11.77	2.85
* See Figure 3c								

LOAD STEPS FOR TEST 3: BROKEN CONDUCTOR (2 BOTTOM ARMS) CONDITION

Load Steps	Vertical Loads, kN			Along-the-Line Loads, kN	
	Sky Wire	Right Circuit			
	PT 1*	PT 6*	PT 7*	PT 10*	PT 12*
3 - 1	3.78	3.89	3.98	1.47	0.87
3 - 2	3.78	3.85	3.98	8.03	8.19
3 - 3	3.78	3.85	3.96	11.97	11.68
* See Figure 3d					

LOAD STEPS FOR TEST 4: HIGH WIND CONDITION

Load Steps	Along-the-Line Load, kN
	PT 10*
4 - 1	20.14
4 - 2	26.74
4 - 3	38.54
* See Figure 3e	

APPENDIX 2

LOAD STEPS FOR VARIOUS LOADING CONDITIONS ON TOWER 13

LOAD STEPS FOR TEST 5: HEAVY ICE AND WIND-ON-ICE CONDITION

Load Steps	Vertical Loads, kN					Along-the-Line Load, kN
	Sky Wire	Left Circuit		Right Circuit		
	PT 1*	PT 2*	PT 3*	PT 5*	PT 6*	PT 10*
5 - 16	0.80	12.24	10.68	11.35	11.21	1.18
5 - 2	0.80	11.17	11.75	11.35	11.24	4.09
5 - 3	0.78	11.19	11.73	11.35	11.19	8.05
5 - 4	0.67	11.06	11.55	11.01	10.86	10.50
5 - 5	0.71	11.08	11.66	11.10	10.99	11.77
5 - 6	0.71	11.08	11.66	11.15	11.04	13.33
5 - 7	0.71	11.06	11.66	11.10	10.99	15.73
5 - 8	0.71	11.06	11.64	11.08	10.99	17.29
5 - 9	0.71	11.04	11.66	11.08	10.97	18.82

* See Figure 4a

LOAD STEPS FOR TEST 6A: BROKEN CONDUCTOR (TOP ARM) CONDITION

Load Steps	Vertical Loads, kN				Along-the-Line Loads, kN	
	Sky Wire	Left Circuit		Right Circuit		
	PT 1*	PT 2*	PT 3*	PT 6*	PT 10*	PT 12*
6A - 1	1.00	2.23	5.36	4.78	1.00	0.69
6A - 2	1.02	2.23	5.36	4.78	6.65	0.69
6A - 3	1.00	2.23	5.36	4.76	13.62	0.67
6A - 4	1.02	2.23	5.38	4.78	13.33	4.81
6A - 5	1.02	2.23	5.38	4.78	13.26	9.08
6A - 6	1.02	2.23	5.38	4.81	13.08	11.73
6A - 7	1.02	2.23	5.41	4.81	13.11	13.77
6A - 8	1.02	2.23	5.38	4.83	13.33	14.91

* See Figure 4b

LOAD STEPS FOR TEST 7: HIGH WIND CONDITION

Load Steps	Along-the-Line Load, kN
	PT 10*
7 - 1	18.69
7 - 2	26.14
7 - 3	37.20
7 - 4	44.52
7 - 5	52.27
7 - 6	55.89
7 - 7	59.65
* See Figure 4c	

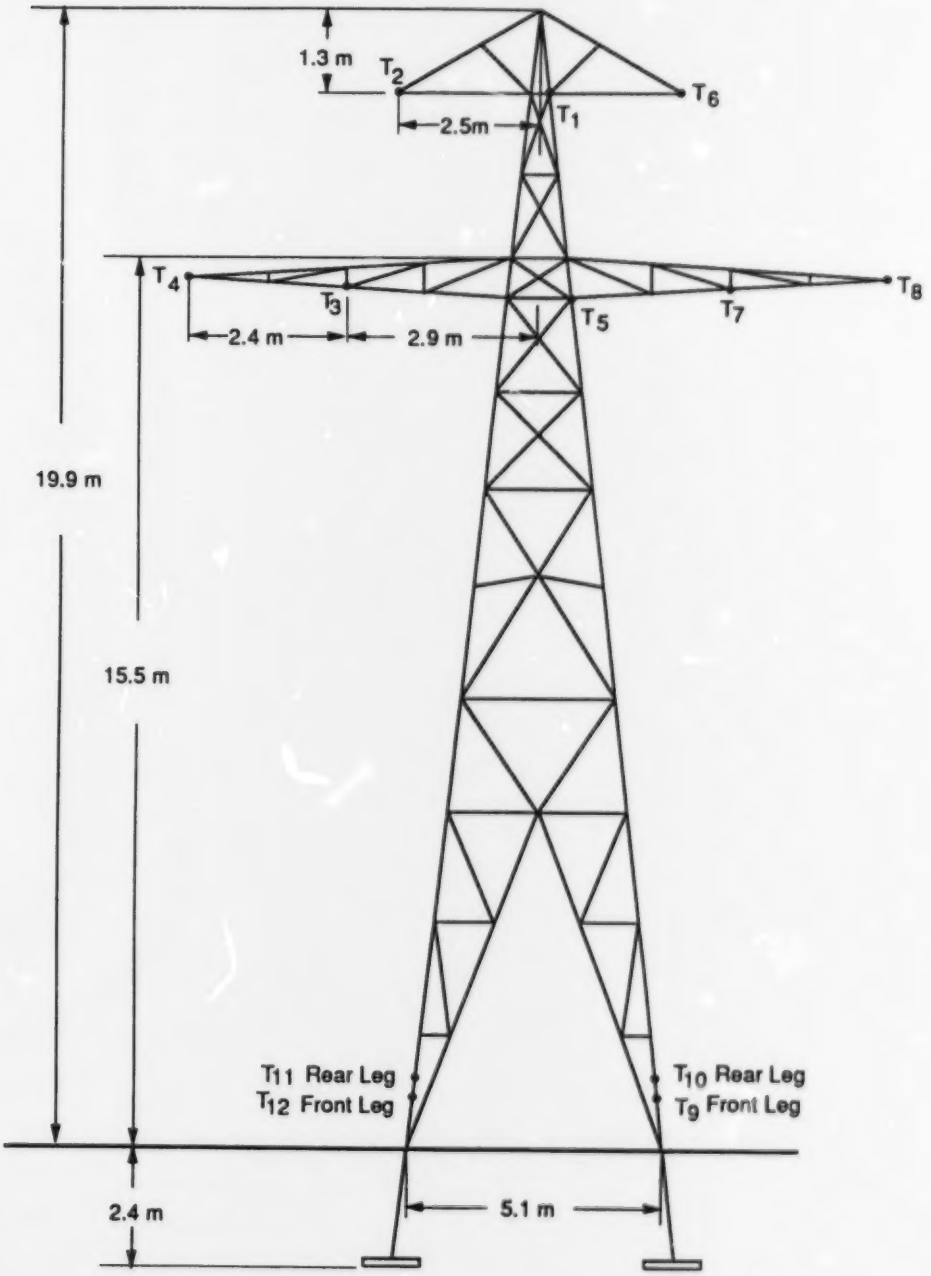
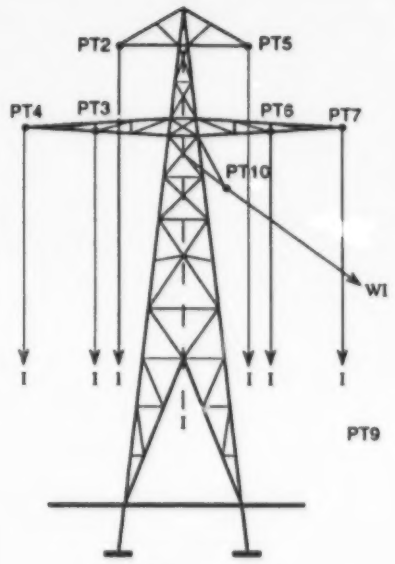


FIGURE 1

DETAILS OF A 115 kV DOUBLE CIRCUIT McGUIGAN-TYPE SUSPENSION TOWER

FIGURE 2

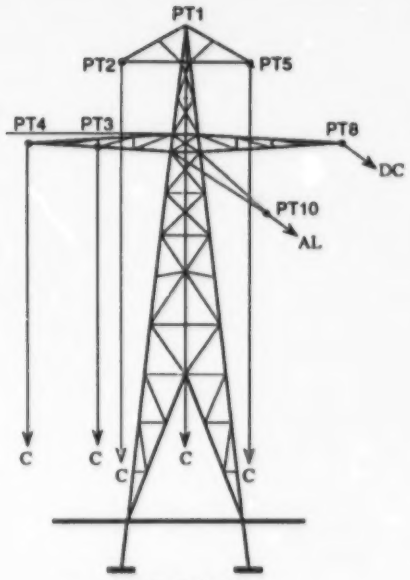
A GENERAL VIEW OF THE McGUIGAN TOWER TYPE



I - Ice
WI - Wind on Ice

FIGURE 3(A)

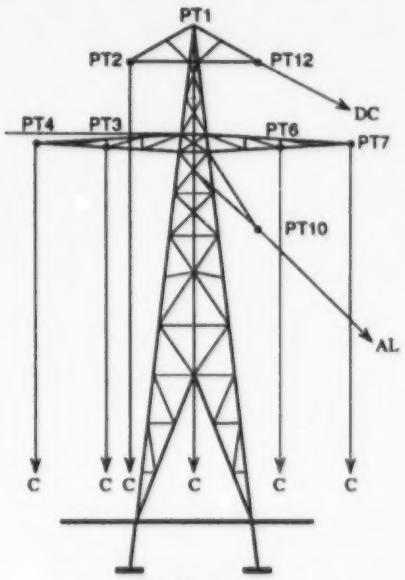
TEST 1
HEAVY ICE AND
WIND-ON-ICE LOADS



C - Conductor Weight
DC - Broken Conductor
AL - Load Due to Line Angle

FIGURE 3(B)

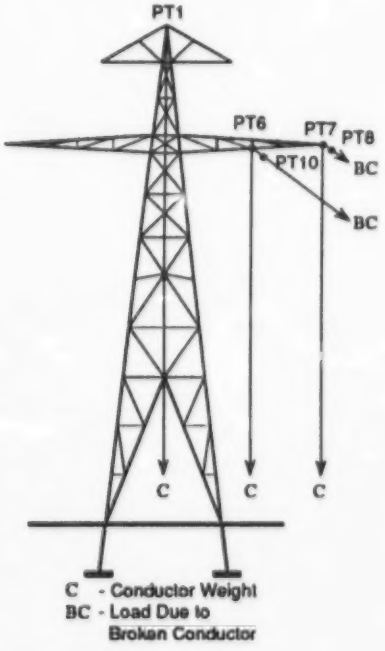
TEST 2A
BROKEN CONDUCTOR
(BOTTOM OUTSIDE ARM) LOADS



C - Conductor Weight
DC - Broken Conductor
AL - Load Due to Line Angle

FIGURE 3(C)

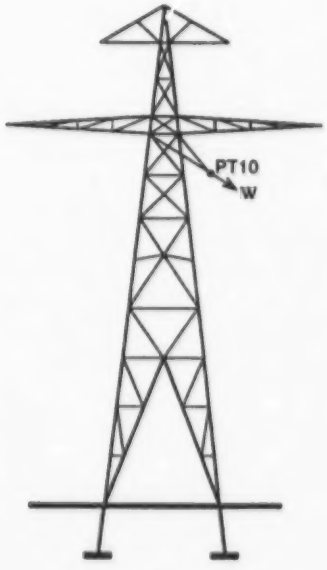
TEST 2B
BROKEN CONDUCTOR
(TOP ARM) LOADS



C - Conductor Weight
BC - Load Due to
Broken Conductor

FIGURE 3(D)

TEST 3
BROKEN CONDUCTOR
(2 BOTTOM ARMS) LOADS



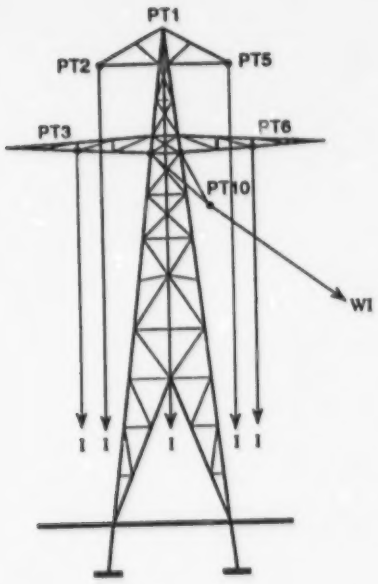
W - Wind

FIGURE 3(E)

TEST 4
HIGH WIND LOADS

FIGURE 3

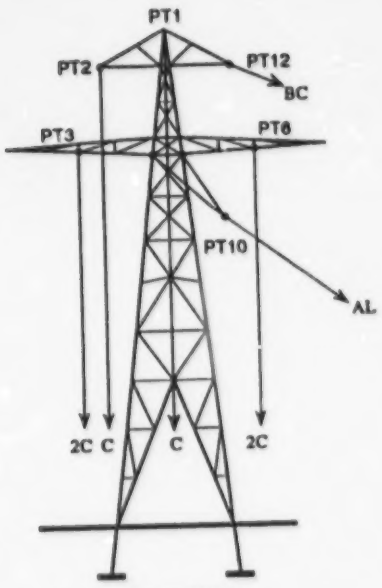
LOAD CONDITIONS FOR TOWER 14



I - Ice
WI - Wind on Ice

FIGURE 4(A)

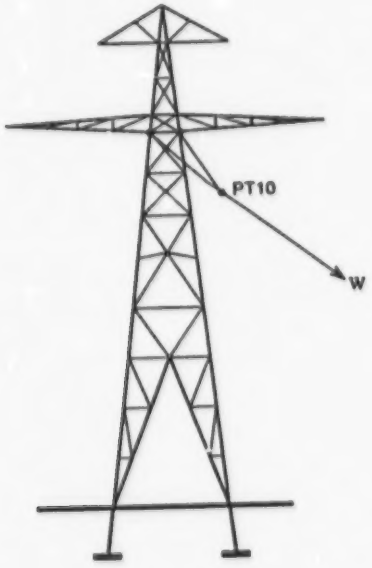
TEST 5
HEAVY ICE AND
WIND-ON-ICE LOADS



C - Conductor Weight
BC - Broken Conductor
AL - Load Due to Line Angle

FIGURE 4(B)

TEST 6A
BROKEN CONDUCTOR
(TOP ARM) LOADS



W - Wind

FIGURE 4(C)

TEST 7
HIGH WIND LOADS

FIGURE 4

LOAD CONDITIONS FOR TOWER 13

90-192

183485-L14-RD

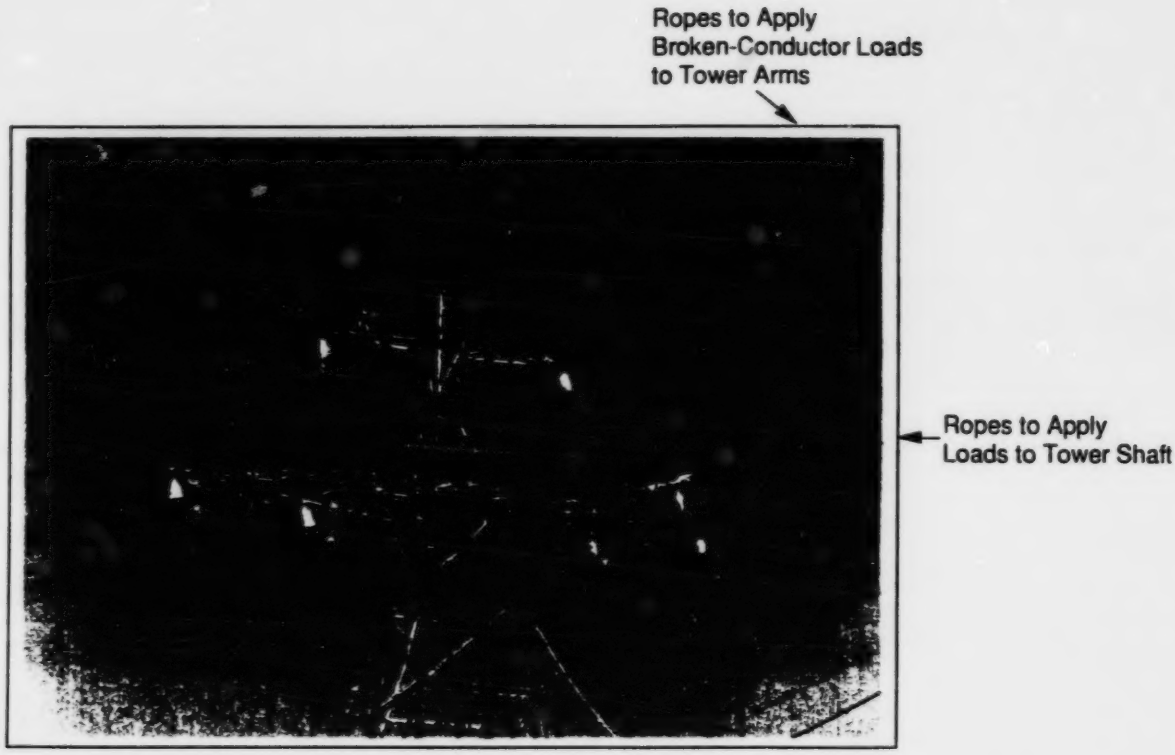


FIGURE 5

ARRANGEMENT TO APPLY ALONG THE LINE LOADS TO TEST TOWERS

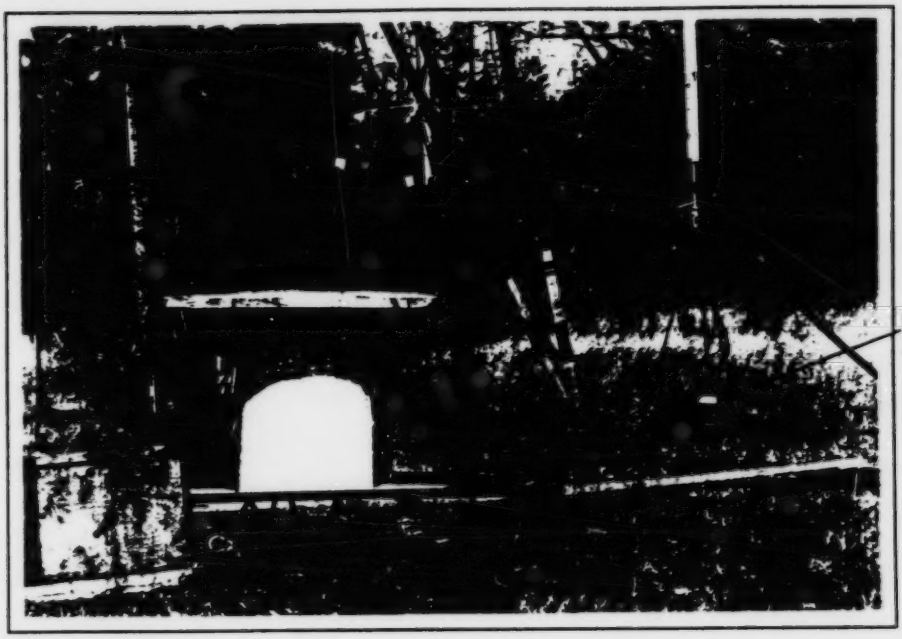


FIGURE 6

ARRANGEMENT TO APPLY VERTICAL LOADS TO TOWER

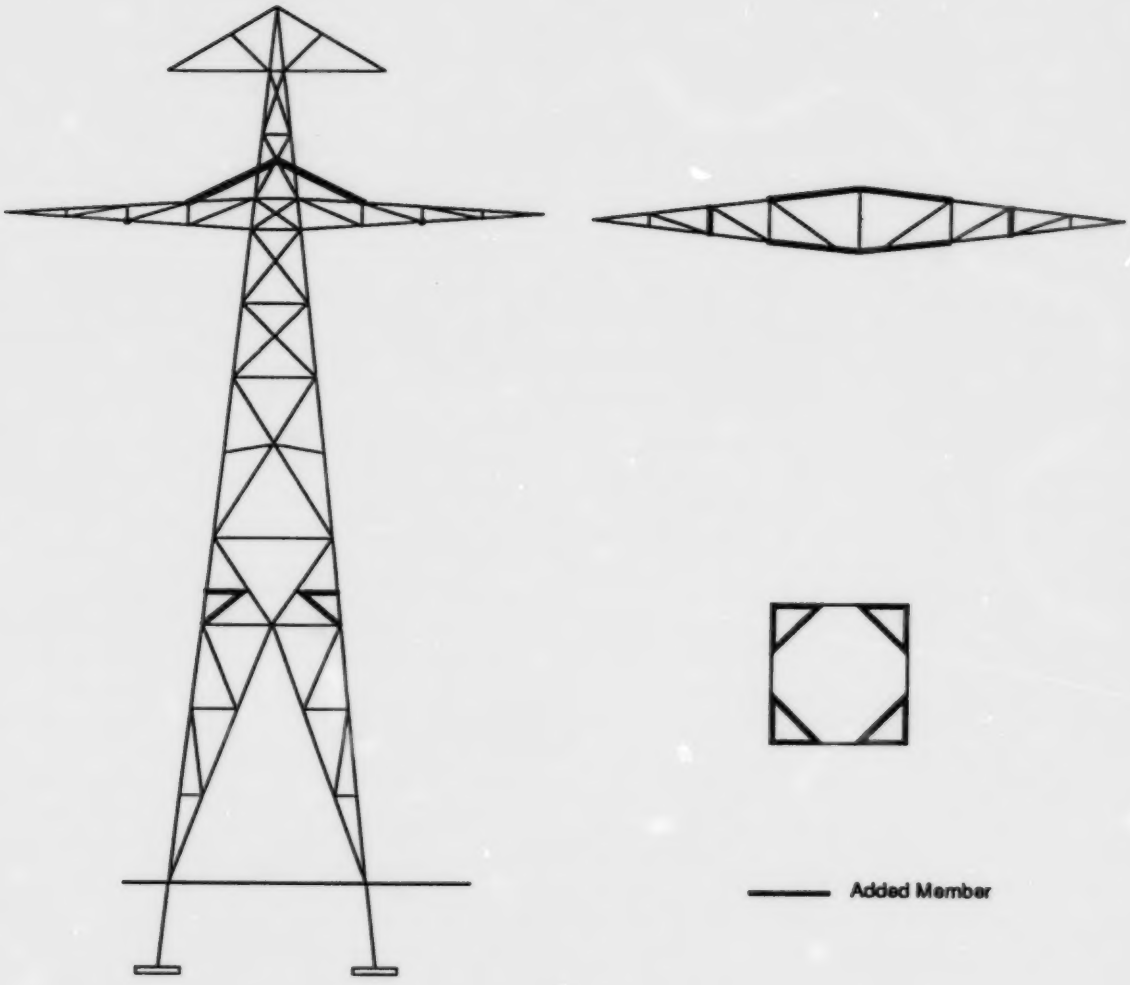


FIGURE 7

REINFORCEMENT TO TOWER 13

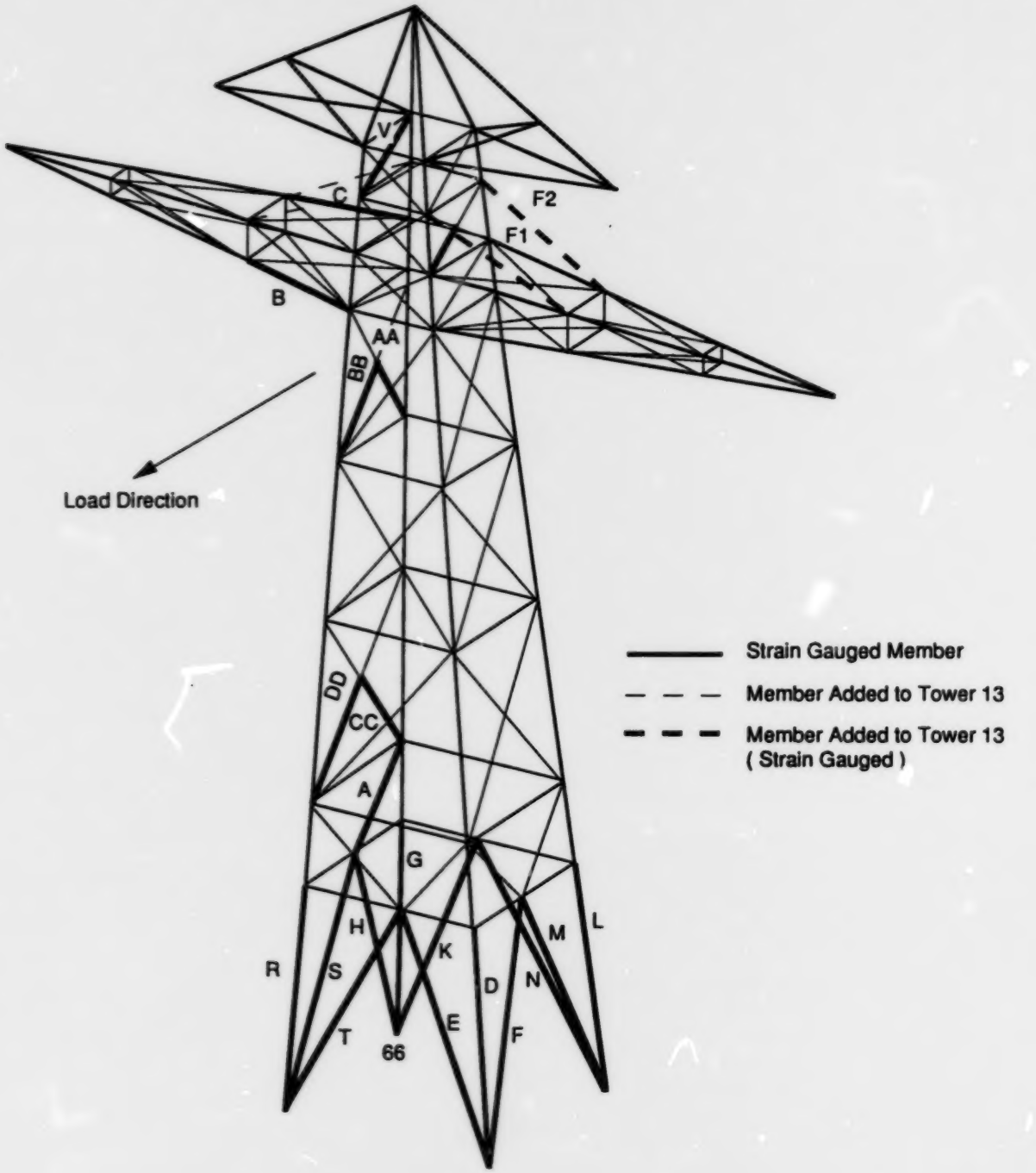
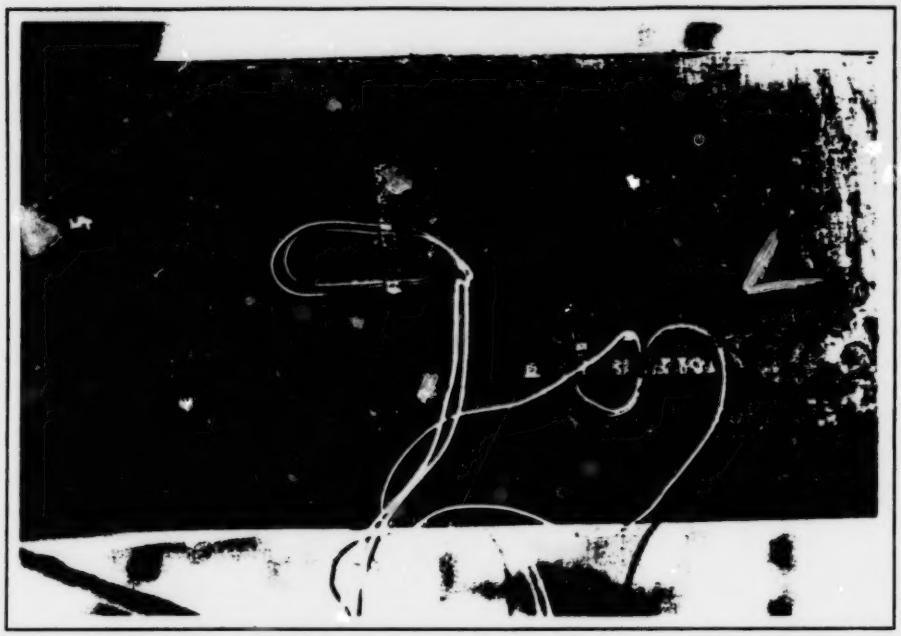


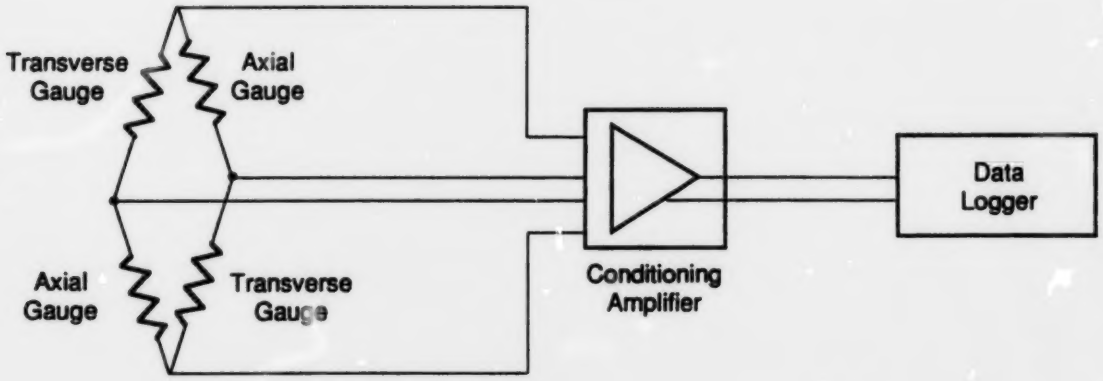
FIGURE 8

STRUCTURAL DETAILS OF A McGUIGAN-TYPE TOWER SHOWING STRAIN GAUGED MEMBERS

90-192
183154-C16-RD



(a) Strain Gauge on a Typical Tower Member



(b) Schematic Diagram of Electrical Configuration

FIGURE 9

A TYPICAL STRAIN GAUGE INSTALLATION

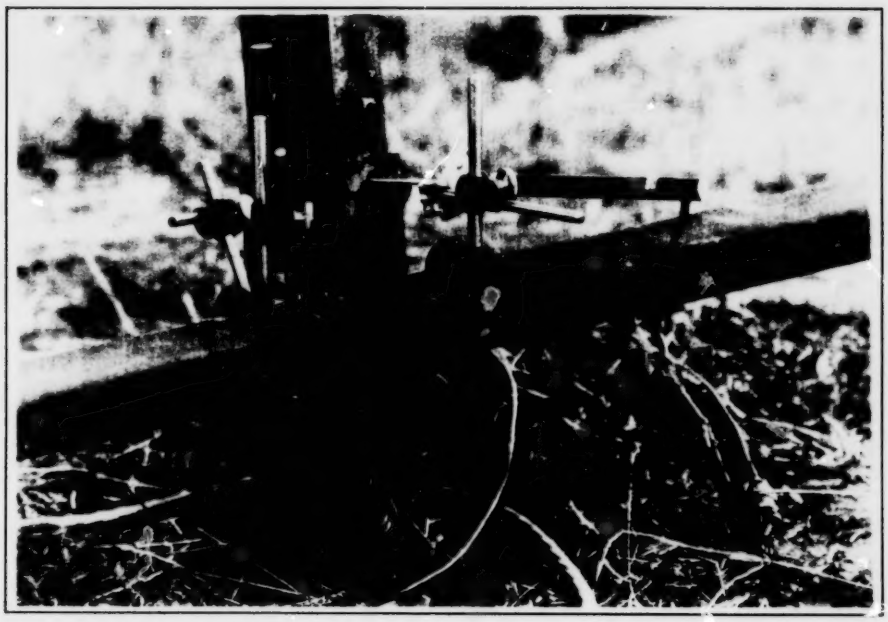


FIGURE 10

A TYPICAL INSTALLATION OF TRANSDUCERS TO MEASURE FOUNDATION DISPLACEMENT

FIGURE 11

TYPICAL VIEWS OF TOWER FAILURE